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Cockpit Design Studies; Standard Cockpit Mockup:
Selection of Subjects for Aircrew Station Design Experimentation

Project TED NAM AE-7052, Part 1

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ABSTRACT

The results of the use of the factor analysis technique as an aid in selecting subjects for aircrew station design experimentation are reported. As a prelude to an investigation concerning the effects of various equipment such as the full pressure suit on operational performance, eleven morphological features were selected which were considered critical in defining cockpit dimensions and arrangement and location of various equipment. However, the probability of obtaining subjects who would fall at approximately the same percentile points, relative to a specific population, in each of these features is extremely small. By the use of factor analysis, it was determined that three basic factors were present and the morphological feature or features with the highest loading on each single factor were selected to represent that factor. This technique allowed the use of a more economical procedure which requires that subjects fall at approximately the same percentile points in five morphological features.

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I. INTRODUCTION

The aircraft cockpit dimensions and equipment arrangement and the location and design features of controls and indicators as employed in naval aircraft have in the past been derived to a large extent from data obtained from U. S. Air Force studies. However, some question has arisen as to the suitability of this data for naval aircraft application. Furthermore, with the consideration of other factors which affect cockpit design such as new ejection seat designs, operation of complex equipment such as fire control and navigational devices, and aircrewmen employment of omni-environmental full pressure suits, the problem is aggravated. Thus, there is a need for a series of studies to consider the overall effects of new aircraft cockpit and protective equipment on operational performance. However, for such studies it is necessary to select subjects who are representative of a particular population in regard to variables which are suspected to be influential in affecting operational performance. In determining the dimensions and the location and arrangement of controls and equipment for aircrew stations, it is obvious that certain morphological features of the operator are important variables in affecting operational efficiency. To determine which features are most critical and to develop a reliable technique for selecting subjects relative to these features for future aircrew station design experimentation, this investigation was implemented.

II. SUMMARY AND CONCLUSIONS

From a survey of anthropometry and aircrew station design literature, eleven morphological features were selected as the most important ones relative to workspace dimensions, viz., height, weight, sitting height, knee height, buttock-leg length, buttock-knee length, elbow-elbow breadth, bideltoid diameter, span, anterior arm reach, and maximum arm reach. Eleven morphological features of forty-two subjects were measured by three anthropometrists. The average of these three measurements was used as the most reliable estimate for each morphological feature and product-moment correlation coefficients were obtained. The intercorrelations of each morphological feature with every other one was factor analyzed and three factors clearly emerged which were interpreted as a "long bone" factor, a "fatty deposit" factor, and an "extension" factor. The morphological feature or features having the highest loadings on each factor and low or zero loadings on other factors were selected to represent that particular factor. Using this procedure five morphological features, height, weight, buttock-leg length, sitting height, and anterior arm reach were considered as the most appropriate to use in lieu of the eleven original ones for the selection of subjects.

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III. RECOMMENDATIONS

1. It is recommended that the five morphological features enumerated above be employed for the selection of subjects for aircrew station design experimentation.

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IV. PROCEDURE

In anthropometric studies only one of the universe of measurements for each morphological feature is sampled. This procedure does not consider the possibility of intra-subject variation, either intrinsic (real) or extrinsic (arising from variation in posture assumed when measurement is taken). In order to obtain a more reliable estimate of each morphological feature, a sample of three measurements for each morphological feature for each of forty-two subjects was obtained. The subjects consisted of 37 civilian employees and 5 naval enlisted personnel of the Air Crew Equipment Laboratory and ranged in age from 19 to 68 (mean age, 34.8; median age, 33.5). Three anthropometrists, practiced to a point where the inter- and intra-anthropmentrist variance was approximately constant after a four week period of training, participated in the procedure; each measured fourteen subjects in the eleven morphological features employing standard anthropometric techniques (4). The three measurements were obtained within a period of one week and at about the same time each day. Thus, this procedure was concerned with extrinsic but not intrinsic variation. To consider this latter source of variation a longer time period between testings would be required.

V. RESULTS AND DISCUSSIONS

In defining workspace dimensions and the configuration of controls and equipment it is apparent that some morphological features are of more importance than others. For example, it seems that buttock-leg length would be a critical determiner of efficiency in operations requiring extended leg action; anterior arm reach, for manipulation of controls or other equipment forward; span, for manipulation of controls to the right or left of the operator, etc. On this basis it would seem that nine morphological features are the most critical ones. These are: sitting height, knee height, buttock-leg length, buttock-knee length, elbow-elbow breadth, bideltoid diameter, span, anterior arm reach, and maximum arm reach. To these nine were added height and weight which are easily and objectively determined and which are of practical value when recruiting potential subjects for measurement.

To select subjects representative of a specific population in these morphological features would require that each subject fall at approximately the same level or percentile in each of these features. The probability of such an event occurring is extremely small and would require extensive sampling. However, there may be fewer than eleven variables operating in this situation because two or more features may be indicating the effects of a single underlying dimension. A statistical technique, factor analysis, which allows one to determine the basic factors underlying the intercorrelation of numerous variables, was used in an attempt to determine the number of factors present.

The intercorrelations of the eleven features were derived as product-moment correlation coefficients in which the mean of the three measurements was used. The intercorrelations were factor analyzed by the Thurstone centroid technique (6) and the three factors that emerged were rotated to simple structure by Harris' extended vector technique (3). Several criteria were utilized to determine at what point the extraction of centroid factors should be discontinued. Humphrey's criterion indicated that three factors were sufficient; Tucker's criterion revealed that four factors were required. Four factors were extracted but the last one was rejected when in the rotation process a clear, consistent pattern could not be obtained because two of the variables (height and knee height) chosen to represent the corners of the primary axes were highly correlated. Furthermore, the communality for height was slightly greater than 1.00 when four factors were present. The factor analysis results are presented ih Figure 1 and Tables 1 - 5.

As indicated in Table 5 three factors emerged clearly. Height and sitting height were the only variables that had moderate or substantial loadings on Factor 1. Elbow-elbow breadth, bideltoid diameter, and weight contained high loadings on Factor 2, and buttock-leg length, buttock-knee length, anterior arm reach, and maximum arm reach were moderately or substantially loaded on Factor 3. The interpretation of each factor is not of primary importance in this study. However, from the pattern and magnitude of the loadings it would appear that Factor 1 might be termed a "long bone" factor; 2, a "fatty deposit" factor;and 3, an "extension" factor.

Having uncovered that the three factors can account for the intercorrelations among the morphological features, the problem remains to choose features which can represent these factors. To determine which variables could best represent each factor, certain criteria were utilized:

1. Choose the variable with the highest loading on one factor but with zero or low loadings on other factors. The standard error of a correlation coefficient of zero is .156 in this study. Therefore, an loading of .312 (2 times the standard error) or less will be considered as zero.

2. Of the variables meeting criterion 1, select those which are most easily and objectively obtained.

Using the above criteria, height and sitting height were selected to represent F_1, weight for F_2, and buttock-leg length and anterior arm reach for F_3. A single variable can represent a factor perfectly if its loading on that factor is 1.00. In practice this never occurs, however, and one must use variables with lower loadings and usually more than one variable. In the case of F_2, the loading of weight was high enough to warrant its use alone. However, for the other two factors, two variables were required. The amount of variance in a variable that is due to a specific factor is the square of the former's loading on that factor. When two or more variables are used to represent a factor, the amount of variance is determined by squaring the loadings and summing over the variables designated to represent that factor. In the present case, the amount of variance for F_1 = .77, $(.717^2 + .509^2)$; F_2 = .82, $(.908^2)$; and F_3 = 1.01, $(.766^2 + .649^2)$. Thus, greater variance is present for F_3 than for the other factors. To counteract this aspect, a weighting procedure could be used. However, in the present context, the "extension" factor would seem to be the most important one because it seems to reflect the operator in action, manipulating his controls and attending to other duties requiring the use of his limbs. Therefore, it would seem that no weighting should be utilized.

The results of a factor analysis are applicable, strictly speaking, only to the sample and measures on which the data was obtained (1, 2, 6). However, Thurstone maintains that if a simple structure solution is obtained for one sample, then the same factors should emerge when a different sample is used if the same variables are present. However, the factor loadings are not invariant with different samples (6). The sample used in this study seems to be approximately representative of U. S. Air Force fighter pilots (4) except in weight, elbow-elbow breadth, and bideltoid diameter. The U. S. Air Force norms are considered here because only one study reports data on naval aircrewmen (5). However, the size of the sample is small and the anthropometric procedures seem to be different from those used in this study.

The ACEL sample contained too many individuals in the upper portion and too few in the lower portion of the distribution for weight, bideltoid diameter, and elbow-elbow breadth. This defect should affect only Factor 2, however. But in view of the fact that the loadings of these three features on F_2 are much greater than any of the other variables, it is doubtful that the loadings would change drastically with another sample. Furthermore, it seems apparent that these three variables are the only ones which seem to have an excess of "fatty deposit" characteristics in common. Therefore, it appears to be justifiable to use these data in selecting subjects for aircrew station design experimentation unless the sample data of the population to be represented is extremely discrepant from the data of the sample used in this investigation.

Therefore, the five morphological features considered above will be used to select subjects for the ACEL aircrew station design experiments. Furthermore, inasmuch as height and weight data are readily available and are easily obtained, it is planned to use these two as screening variables to select for further measurement on the other three morphological features only those individual having the percentile values required. Thus, fewer individuals will have to be sampled in this procedure, resulting in economy in time, effort, and money.

VI. REFERENCES

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Table 1

Correlation Matrix and Third Centroid Factor Residuals.
Standard Error of a Correlation Coefficient of Zero = .156.

Morphological Feature	1	2	3	4	5	6	7	8	9	10	11
1. Span		-.057	.036	-.020	-.088	-.077	.011	.060	.048	.003	-.035
2. Height	.62		-.161	.061	.109	.150	.049	-.055	.043	.020	.034
3. Buttock-leg length	.62	.33		.114	.089	-.005	-.087	.023	-.010	-.012	-.011
4. Sitting Height	.38	.67	.44		-.154	-.044	-.098	-.007	-.028	.052	.022
5. Knee height	.57	.87	.80	.26		-.016	.040	-.005	-.067	-.132	.104
6. Buttock-knee length	.53	.74	.86	.34	.71		.007	-.034	-.109	-.034	.052
7. Elbow-elbow breadth	.06	.07	.20	.17	.03	.25		.028	.027	-.073	.037
8. Bideltoid diameter	.28	.27	.35	.44	.17	.30	.67		-.007	.075	-.022
9. Anterior arm reach	.67	.66	.80	.29	.70	.67	.05	.13		.026	-.006
10. Maximum arm reach	.63	.68	.78	.44	.62	.74	.04	.32	.80		-.022
11. Weight	.21	.28	.51	.44	.32	.53	.80	.74	.24	.32	

RESIDUALS

Correlation Coefficients

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Table 2

Centroid Factor Matrix

Morphological Feature	I	II	III	Communality
1	.679	.282	-.138	.560
2	.785	.237	-.560	.986
3	.849	.232	.410	.943
4	.588	-.160	-.331	.480
5	.767	.435	-.100	.788
6	.846	.229	.229	.821
7	.407	-.684	.243	.693
8	.571	-.613	-.039	.703
9	.753	.468	.151	.809
10	.799	.340	.086	.761
11	.672	-.632	.236	.906

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Table 3

Extended Vector Matrix

Morphological Feature	$\frac{1}{aji}$	Factor I	Factor II	Factor III
1	1.473	1.000	.415	-.203
2	1.274	1.000	.302	-.713
3	1.178	1.000	.273	.483
4	1.701	1.000	-.272	-.563
5	1.304	1.000	.567	-.130
6	1.182	1.000	.271	.271
7	2.457	1.000	-1.681	.597
8	1.751	1.000	-1.073	-.068
9	1.328	1.000	.622	.201
10	1.252	1.000	.426	.108
11	1.488	1.000	-.940	.351

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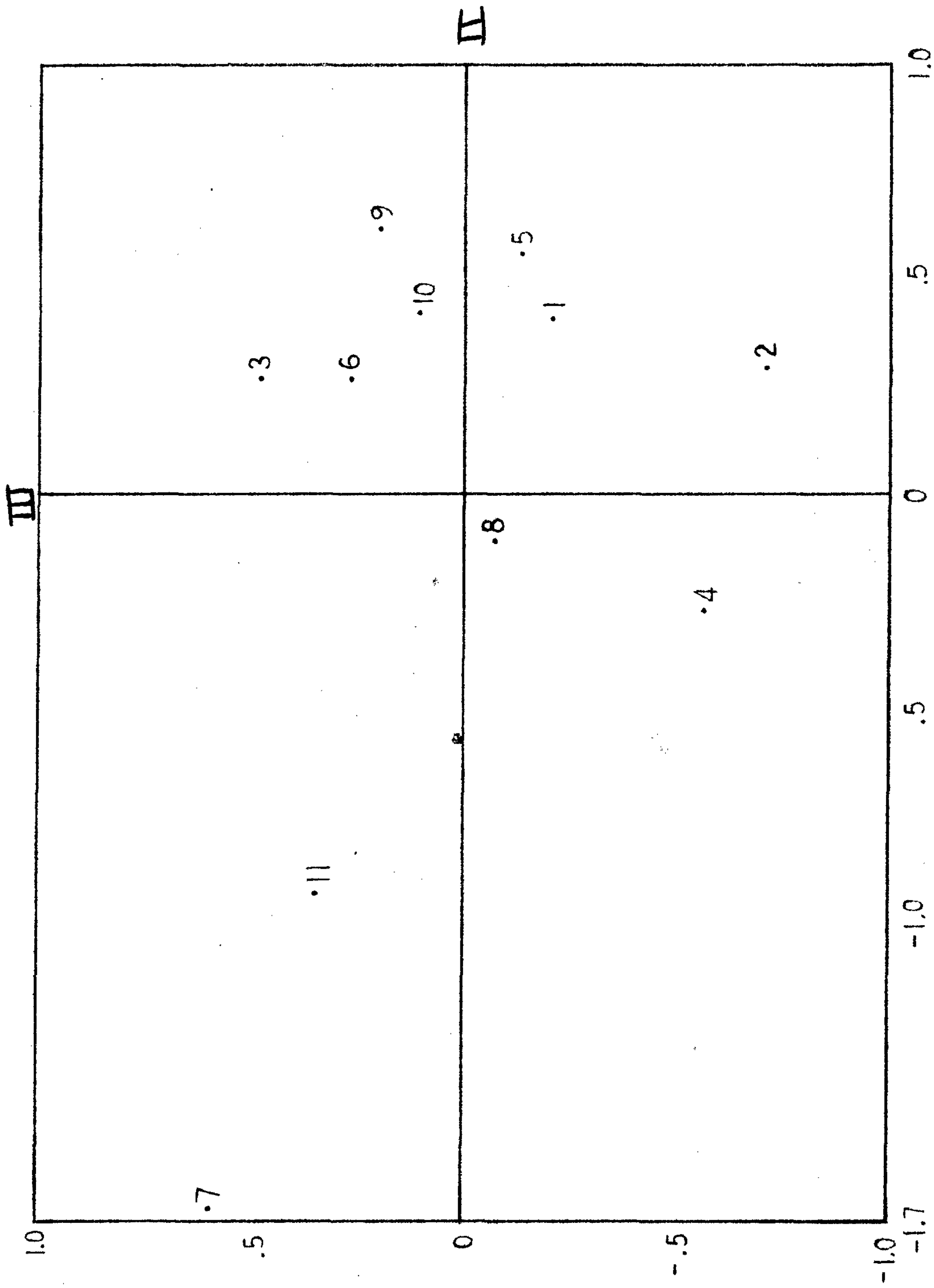

FIGURE 1. PLOT OF THE EXTENDED VECTOR LOADINGS. VARIABLES 7, 2, AND 9 WERE SELECTED TO REPRESENT THE CORNERS OF THE THREE PRIMARY AXES.

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Table 4

Transformation Matrices for the Primary Factors (T_p) and for the Simple Factors (T_s), and the Cosines of Angular Separation Between the Simple Axes (C_s)

T_p

	P_1	P_2	P_3
I	.791	.489	.837
II	.239	-.822	.521
III	-.564	.292	.168

C_s

	I	II	III
I	.999	-.005	-.691
II	-.005	.999	-.018
III	-.691	-.018	1.000

T_s

	I	II	III
P_1	.291	.461	.393
P_2	-.163	-.837	.507
P_3	-.942	.293	.767

Table 5

Rotated Factor Loadings on the Oblique Simple Axes (V)

Morphological Feature	Factor I	Factor II	Factor III	Communality*
1	.282	.037	.304	.560
2	.717	.000	.000	.987
3	-.177	.317	.766	.941
4	.509	.308	-.104	.480
5	.246	-.040	.445	.785
6	-.007	.265	.624	.818
7	.001	.831	.000	.691
8	.303	.765	-.116	.703
9	.001	.000	.649	.809
10	.096	.109	.552	.759
11	.076	.908	.125	.905

*Communalities reproduced by the formula, $C = V(C_s)^{-1}V'$